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NIKE APACHE PERFORMANCE HANDBOOK

Reed B. Jenkins

Goddard Space Flight Center
Greenbelt, Maryland

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NIKE APACHE PERFORMANCE HANDBOOK

by

Reed B. Jenkins

Goddard Space Flight Center

SUMMARY

The configurational and mass characteristics of the Nike Apache two-stage solid-propellant sounding rocket system are described. Aerodynamic and performance data on the Nike Apache are presented for the various configurations commonly flown. Calculations of vehicle stability and of velocity, altitude, and range versus time and payload weight are presented graphically for use in determining maximum performance of any given configuration as a function of various parameters. Flight test data on lateral and longitudinal accelerations during the boost phases are included.

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INTRODUCTION

As the result of a successful flight test program, the Nike Apache rocket vehicle has been added to the group of sounding rockets approved by NASA. This vehicle consists of a Nike M5-E1 first stage and a Thiokol TE-307 Mod II (Apache) second stage. The Nike Apache is capable of lifting payloads in the 50 to 80 pound range to altitudes in the region of 100 to 150 statute miles (160 to 240 kilometers) when launched at an elevation angle of 80 degrees from a sea level missile test facility.

The data contained in this report are designed for use by scientific experimenters, vehicle managers, and range safety personnel. The data are subject to the limitations noted within the report, and to revision in the event of weight or configurational changes.

VEHICLE DESCRIPTION

The Nike Apache is a two-stage solid-propellant unguided sounding rocket (Figure 1). The vehicle is stabilized by four fins (on each of the two stages) arranged in a cruciform configuration. The stages are connected by a conical transition section that is bolted to the first stage and slip-fits into the nozzle of the second stage. Separation is achieved at burnout of the first stage by differential drag forces. There is no mechanical restraint between the second stage and the transition assembly in the axial direction. Ignition of the second stage is normally delayed for 16.5 seconds after burnout of the first stage to reduce aerodynamic heating and drag in the high density, low altitude region.

The first-stage motor is the standard Nike M5-E1 booster currently used by NASA in several vehicles. Since its characteristics are generally well known, a description is not given here.

The Apache TE-307 motor was developed by Thiokol Chemical Corporation for use as a single stage (Mod I) or an upper stage (Mod II) solid-propellant rocket booster. In external appearance, it is almost identical to the Cajun. In fact, most of the hardware used is identical and interchangeable. The external difference is the nozzle extension (Figure 2). On the Cajun this extension is fabricated of steel; but it was found that the steel would not give satisfactory service with the higher exhaust gas temperature of the Apache. The Apache extension is composed of a steel can with a phenolic liner,

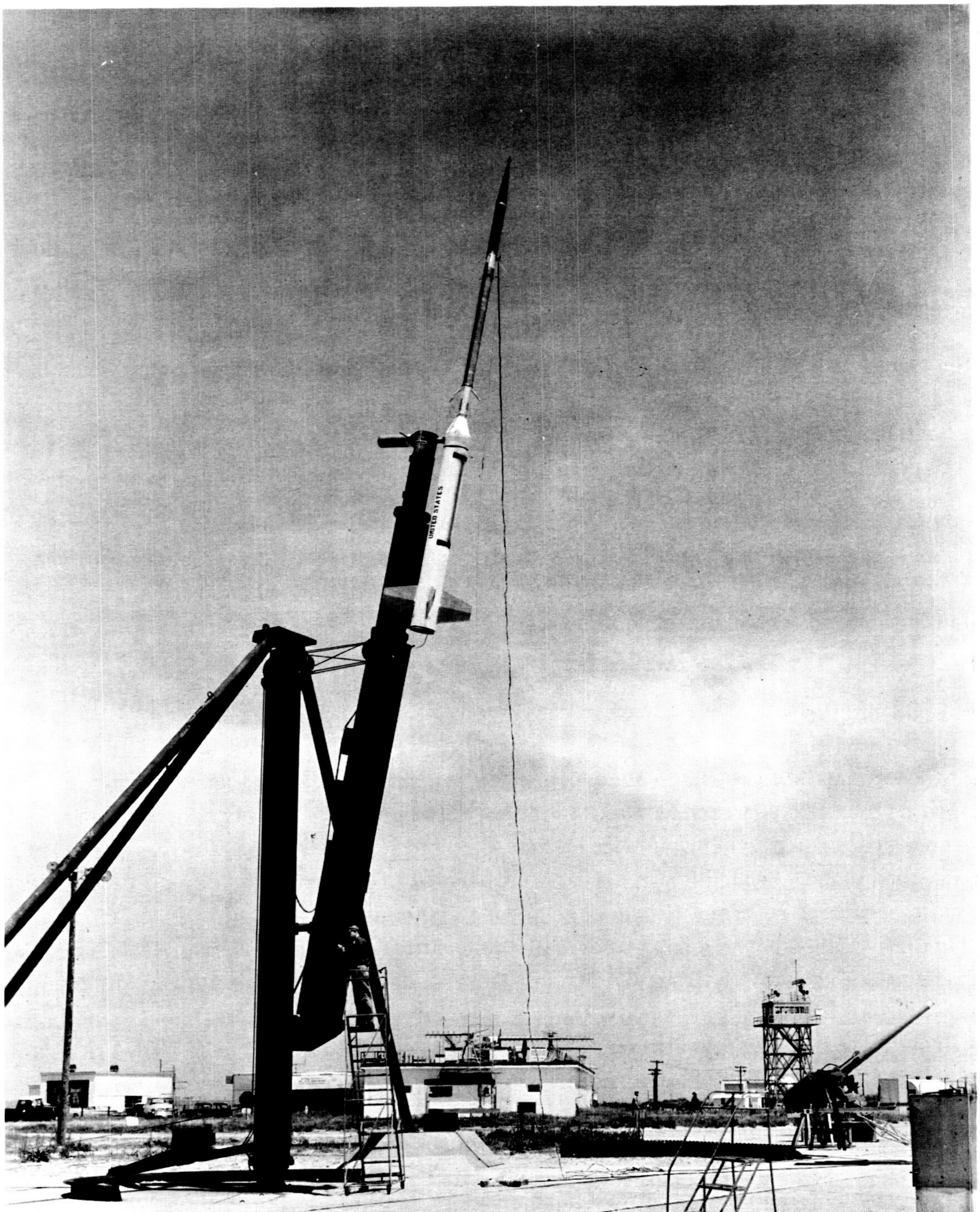


Figure 1—Nike Apache on launcher.

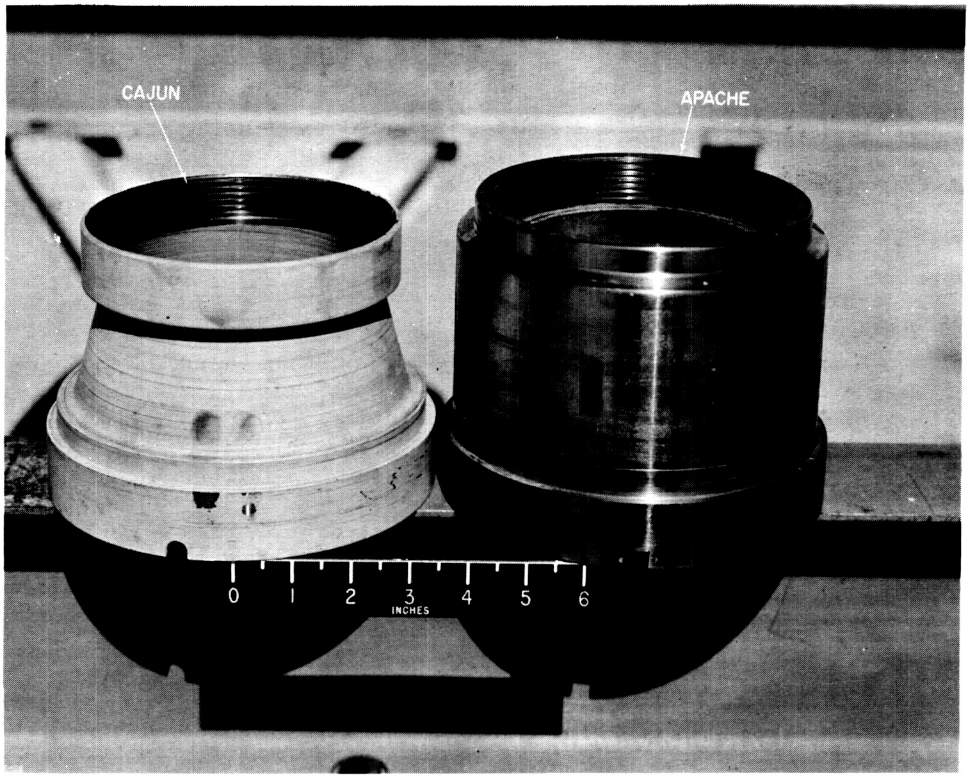


Figure 2—Nozzle extensions.

which is bonded to the steel and secured from rotation or expulsion by three roll pins. Although bulkier in dimension, the Apache extension is somewhat lighter than the Cajun extension.

The primary internal difference between the Cajun and the Apache is the propellant. The Apache is loaded with an aluminized polyurethane propellant that has a higher specific impulse and a longer burning time than that powering the Cajun. This gives the Apache a considerable performance improvement over the Cajun. In addition to the higher performance, the Apache should prove to be more reliable, in terms of lower probability of motor failure, than the Cajun: The operating pressure of the Apache is about 300 psi below that of the Cajun, while the case thicknesses are the same. Higher reliability is, however, a rather nebulous term in this case, as NASA has had no known Cajun failure due to case rupture.

A second internal variation is the igniter. The Apache uses a "pyrogen" igniter (Figure 3), which was developed by Thiokol for use on certain propellants to achieve unpressurized altitude ignition. The pyrogen igniter is actually a small rocket motor that operates for about 100 milliseconds. Its purpose is to provide both the temperature and pressure required to ignite the grain. For each propellant there is a certain threshold temperature and pressure below which ignition will not occur. It was found that the standard Cajun igniter would not provide these threshold conditions for the Apache propellant at high altitudes.

The pyrogen igniter is initiated by a pyrotechnic delay squib similar to that used on the Cajun. This delay squib is fired at launch and burns for a predetermined time before firing the pyrogen igniter. Because of the necessity for housing the igniter in a steel case and the length of the delay squib, a penalty of about 5 pounds is imposed on the vehicle burnout weight. This could be avoided by deleting the squib and firing the Apache with a timer housed in the payload section. For current NASA applications the weight penalty has not been deemed serious enough to warrant the change.

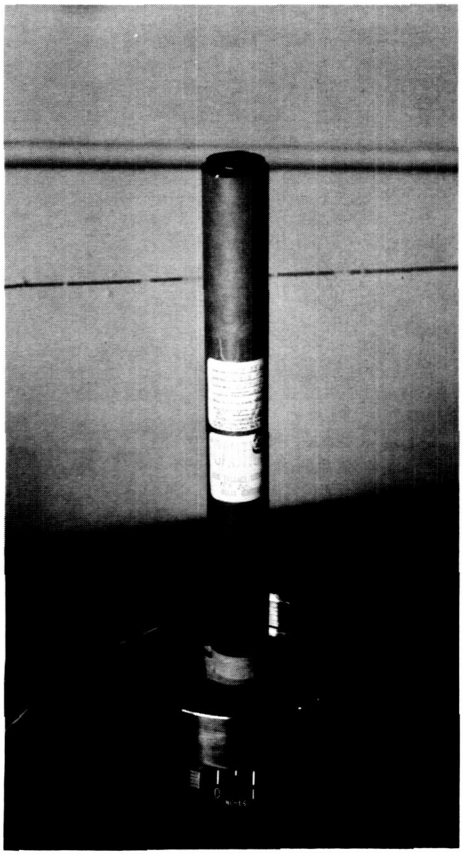


Figure 3—Apache pyrogen igniter.

The Nike-to-Apache adapter and the fin assembly are identical to those used on the Cajun and are now interchangeable. A slight modification of the fin assembly has been made to accommodate the increased dimensions of the Apache nozzle extension. All assemblies now being procured are interchangeable (Figure 4).

The Apache motor and fin assemblies are fabricated of aluminum with the exception of the following components, which are fabricated of steel:

1. Nozzle and nozzle extension (liner is graphite)

2. Igniter housing (attached to head cap)

3. Fin leading edge cuffs

4. Fin shroud fairing ring

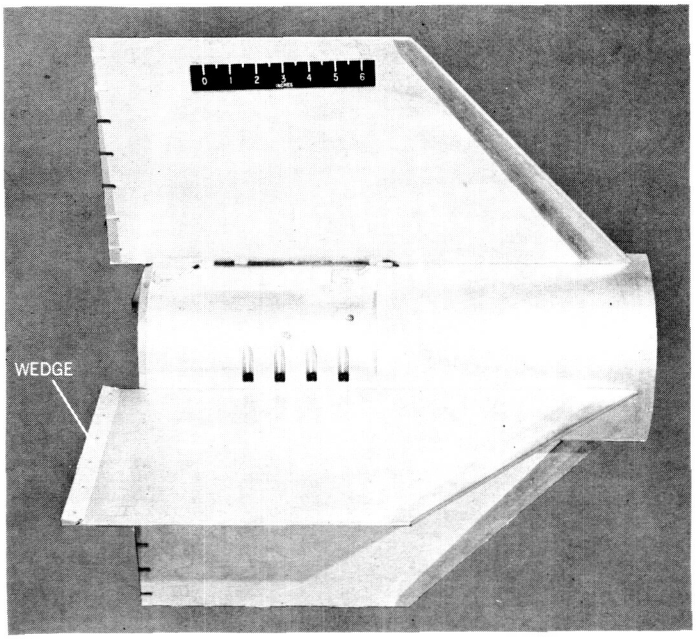


Figure 4—Nike Apache fin assembly.

Because of the relatively small amount of ferrous metals the Apache, like the Cajun, can be used for boosting payloads carrying scientific instrumentation that cannot be flown on steel-cased motors.

Figure 5 shows the Nike Apache vehicle and gives the overall dimensions.

The system's weights and centers of gravity are given on page 5. These data are approximate and vary slightly from round to round. The variations are due to casting and extrusion techniques used in propellant and case manufacture, and do not significantly affect the flight characteristics of the system.

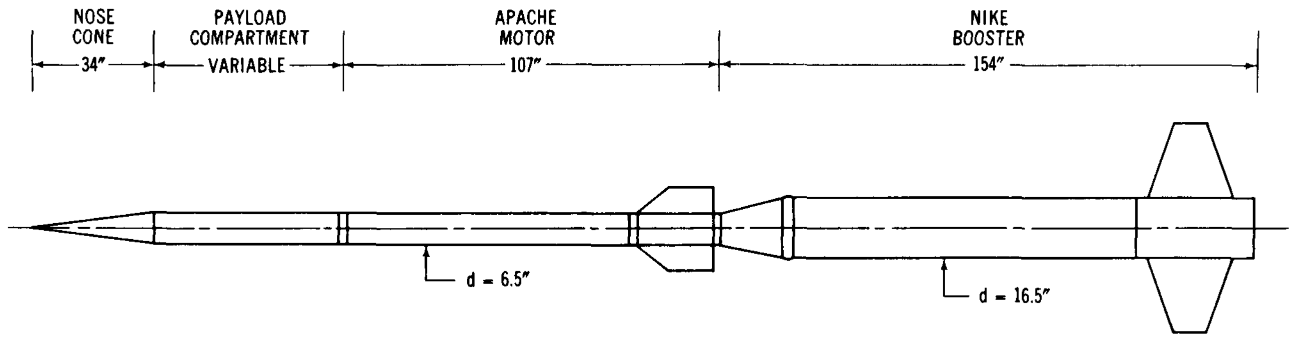


Figure 5—Nike Apache dimensions.

Weights (lb):	
Apache motor (empty)	60.5
Propellant	131.0
Loaded weight (no payload)	191.5
Fin assembly	26.0
Flight weight (less payload)	217.5
Nike motor (empty)	431
Propellant (mass consumed)	764
Loaded weight	1195
Fins	95.0
Nike Apache adapter	27.0
Flight weight	1317.0
Launch weight (less payload)	1534.5

Centers of gravity (in.):*	
Apache motor (no fins)	
Full	56.3
Empty	50.3
Apache motor (with fins)	
Full	49.2
Empty	38.1
Nike motor	67.5
Propellant	83.5
Fins	18.4
Adapter	162.0

*Dimensions given in inches from base of motor concerned.

The general physical characteristics of the Apache may be summarized as follows. Exact data pertaining to propellant formulation, total impulse, chamber pressure, burning time, and thrust are classified; the data given here, therefore, indicate the general category of performance and are not exact:

Apache weight:	(As given above)
Dimensions (in.):	
Motor length	107.94
Diameters	
Motor	6.5
Head cap	6.75
Maximum (nozzle extension)	7.135

Propellant	aluminized polyurethane
Average thrust (lb)	≈5000
Average P_c (psi)	≈700
Burning time (sec)	≈6
Impulse (lb/sec)	≈30,000

Figure 6 shows the Apache in a clean flight configuration with the approximate maximum and minimum payload lengths expected to be flown. The payload volume inside the cylindrical sections for the 10 inch and 50 inch extensions is 440 and 2200 cubic inches respectively. The volume inside the standard cone is about 500 cubic inches. In actual practice, only about one-half the cone volume may be conveniently used for instrumentation; thus the available payload volume for the Apache can

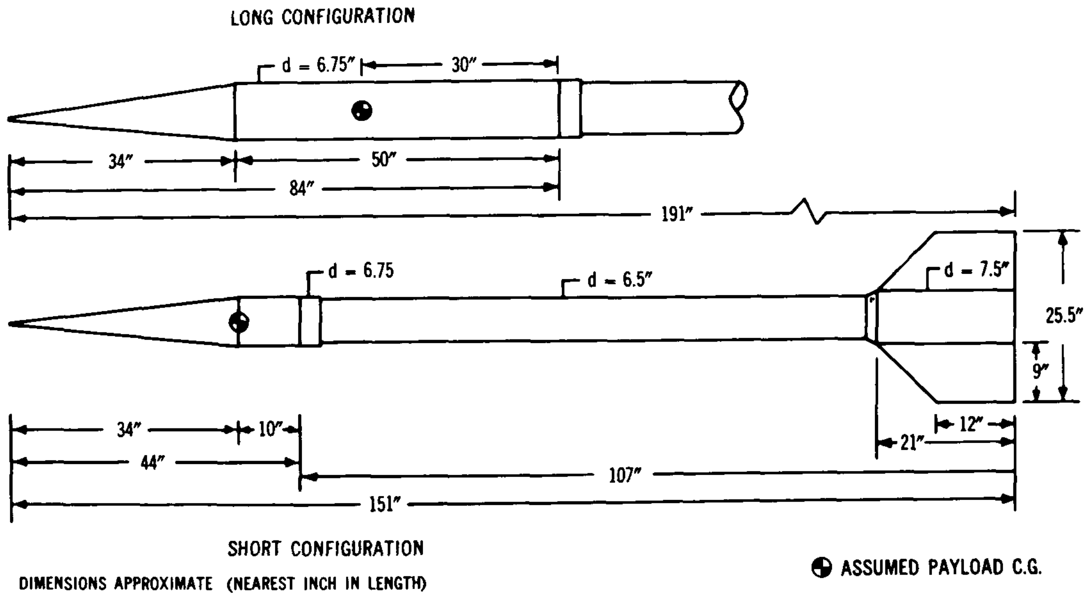


Figure 6—Apache clean flight configuration.

be considered to lie between 690 and 2450 cubic inches, with a maximum internal diameter of just under 6.5 inches.

Oversized and nonstandard configurations may be flown; however, each should be analyzed thoroughly to insure compatibility with the flight environment to which it will be subjected. Special care should be taken to avoid the possibility of structural divergence of the Apache-plus-payload during the Nike boost phase.

AERODYNAMIC CHARACTERISTICS

Much of the aerodynamic data on the Cajun applies to the Apache, since the external configuration of both vehicles (exclusive of payload) is identical. Reference 1 has been widely used as a source of Cajun data; however, several modifications of the drag and lift data have been made recently (see References 2 and 3). Figure 7 gives the drag coefficients for the Apache for the various configurations discussed below. Transonic and subsonic drag are estimated, as the second-stage Apache normally does not fly at Mach numbers below 1.5 except at extreme altitudes where drag forces are negligible because of the low density of the atmosphere.

It is necessary to make certain assumptions as to external configuration in order to estimate drag. The cone chosen for analysis has an 11 degree total angle and a 6.75-inch-diameter base. The 11 degree cone is preferred to the blunter cones sometimes flown on Cajuns for two reasons: First, the 11 degree cone has less drag and thus gives slightly better performance. Second, the more slender cone has a lower lift coefficient and a center of lift further aft for the same total payload length (Reference 3). This tends to improve the static stability of the vehicle and also results in lower bending moments on the Apache motor during first-stage boost. All the curves in Figure 7 are based on this cone.

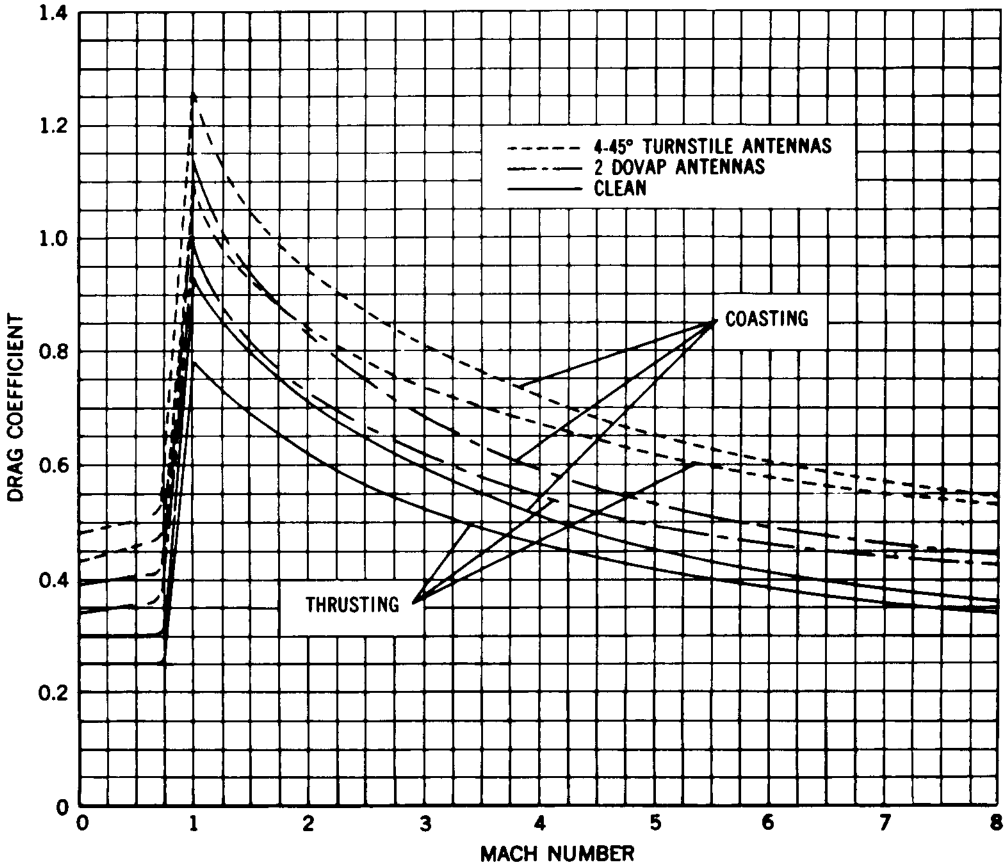


Figure 7—Drag coefficient (11 degree nose cone; reference area, 33.2 in.^{2}).

Drag coefficient contributions were calculated from two types of antennas that have been flown on the Nike Cajun.* The antennas considered were DOVAP and four turnstile (Figure 8). Other types of antennas are flown, but the drag of these usually is similar to one of the foregoing. The DOVAP antennas are strapped to the motor case 180 degrees apart, and the turnstile antennas are usually swept at 45 degrees. The drag coefficient penalty for each of these configurations has been computed and is reflected in the curves of Figure 7.

The lift and the center of pressure were calculated by the method of Reference 4† and are shown in Figures 9 and 10. The lift coefficient is approximately true for all payload lengths (with the 11 degree cone attached) normally flown. Center of pressure, though, is a function of total length. Maximum and minimum payload lengths were assumed in order to establish a range of centers of pressure that would account for most circumstances under which the Apache would be flown. A 10 inch cylindrical section yielding a minimum payload length of 44 inches was added to the standard 34-inch-long 11 degree nose cone, and a 50 inch cylindrical extension was added for a maximum length of 84 inches (Figure 6). It is felt that the majority of the payloads to be flown on the Apache will fall within these

*Lane, John H., "Unpublished Data on Nike Cajun Sounding Rocket System." NASA-GSFC, 1961.
†Also the method given by Lane (see footnote above).

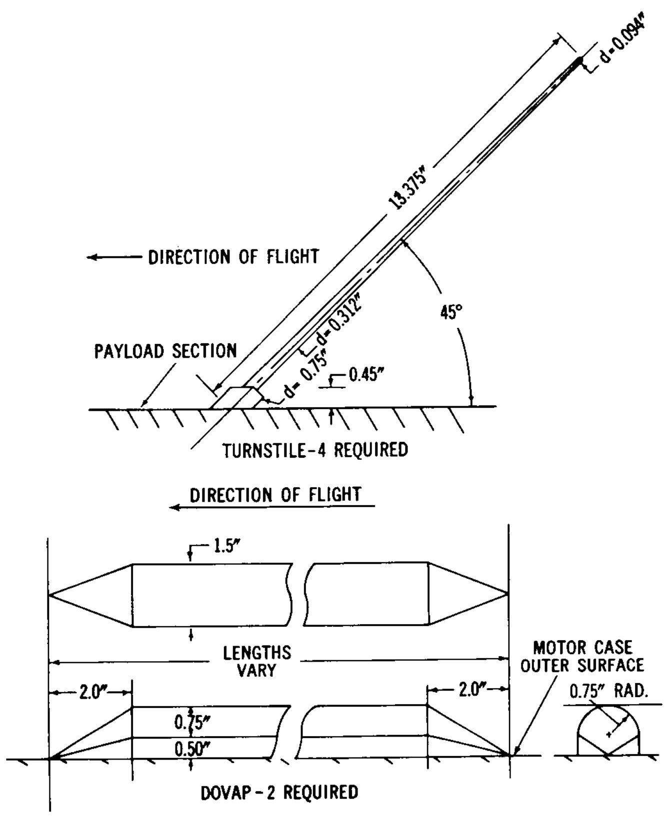


Figure 8—DOVAP and turnstile antennas.

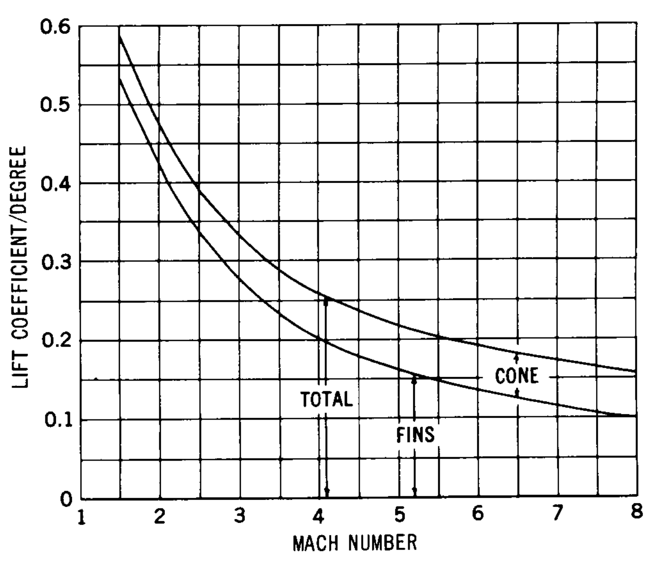


Figure 9—Lift coefficient (reference area, 33.2 in.^{2}).

limits. It is recommended that payloads longer than 84 inches not be flown, since experience with the Cajun has shown that, with long payloads, a high probability of vehicle failure exists because of structural divergence during first-stage boost.

The centers of pressure, as calculated for the maximum and minimum length Apaches, are shown in Figure 10. A linear interpolation may be employed to estimate the center of pressure for any length other than the extremes. Likewise, the center of gravity for any given payload weight and length may be obtained from Figure 11.

The center-of-pressure and center-of-gravity data have been combined in Figures 12 and 13 for convenience in estimating the aerodynamic static margin (or the weathercock stability) for any particular flight. It will be noted that the Apache has a considerable degree of static stability for any of the payload lengths and weights considered. Insufficient static stability might be encountered if light payloads (i. e., < 50 lb) were flown in very long payload compartments. This is generally unlikely to happen in actual practice.

Dynamic stability of the Apache can be maintained by spinning the vehicle at a relatively high roll rate: The recommended roll rate is 5 rps at burnout of the Apache stage. Roll is obtained either by canting the fins or by installing wedges on the trailing edges of the fins; NASA uses the latter method on the Apache. A typical example of installed wedges can be seen in Figure 4. Excellent stability in the atmosphere and in space has been demonstrated by Apache flights in which a 5-rps roll rate was achieved. Figure 14 shows the actual roll-time histories for two flights in which the maximum roll rate was 5 rps. These flights appear to typify the differences between transient roll histories of canted-fin vehicles and those of vehicles flown with trailing edge wedges. Those flights

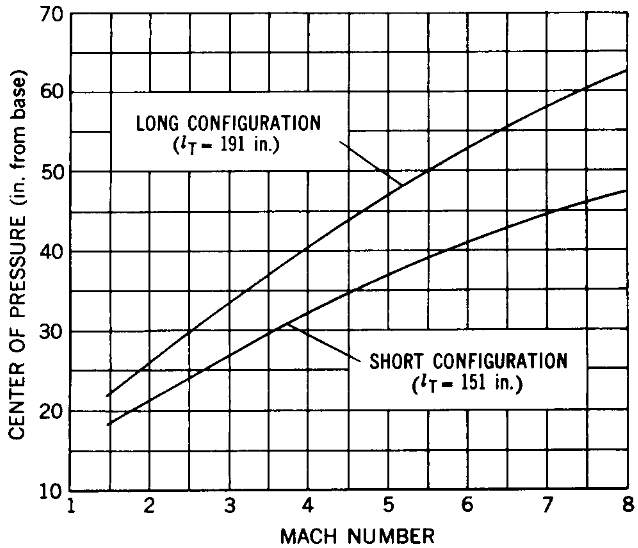


Figure 10—Center of pressure vs. Mach number.

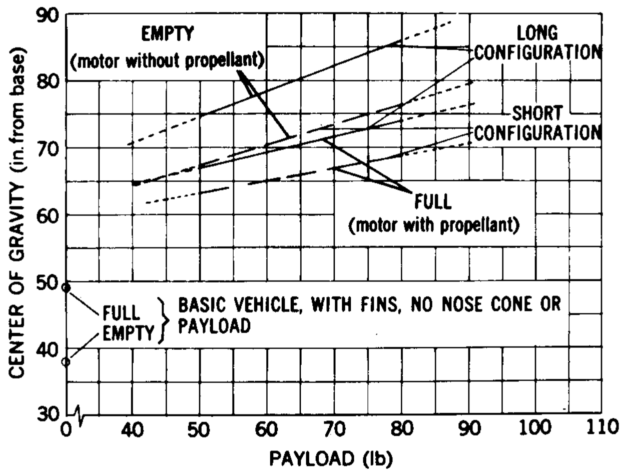


Figure 11—Center of gravity vs. payload weight.

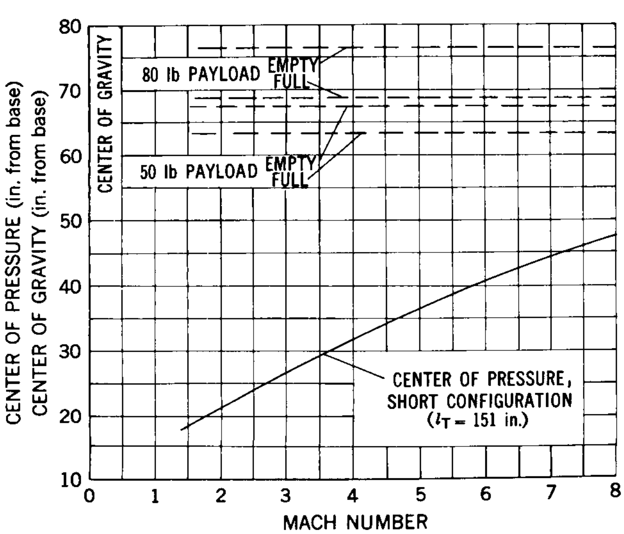


Figure 12—Centers of pressure and gravity, short configuration.

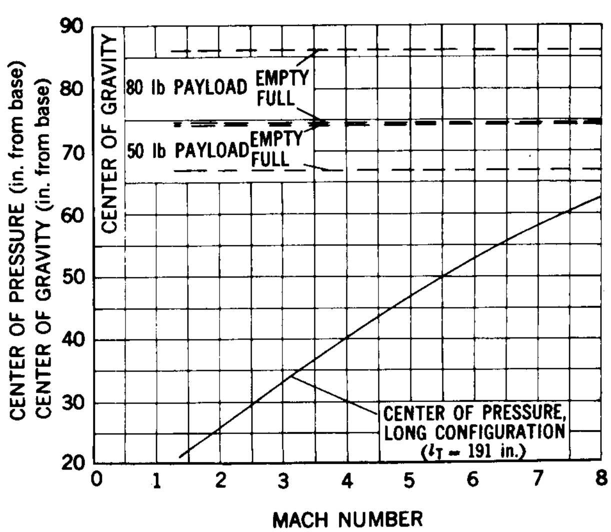


Figure 13—Centers of pressure and gravity, long configuration.

made at roll rates lower than 5 rps have exhibited large coning motions and/or tumbling of the vehicle as it exists in the atmosphere. If experimental considerations preclude the use of a rolling vehicle, then every effort should be made to keep the spin at as low a rate as possible. The fin assembly manu-ufacturer provides alignment and warp data on each set of fins, and these data should be considered in selecting fins for a no-roll vehicle. The experimenter should recognize that, without roll, there is a good probability of poor space attitude. *In no case should the vehicle be intentionally rolled to rates at second-stage burnout in the vicinity of 2 to 3 rps, as pitch-roll resonance will occur and may result in vehicle breakup and/or poor attitude in space.*

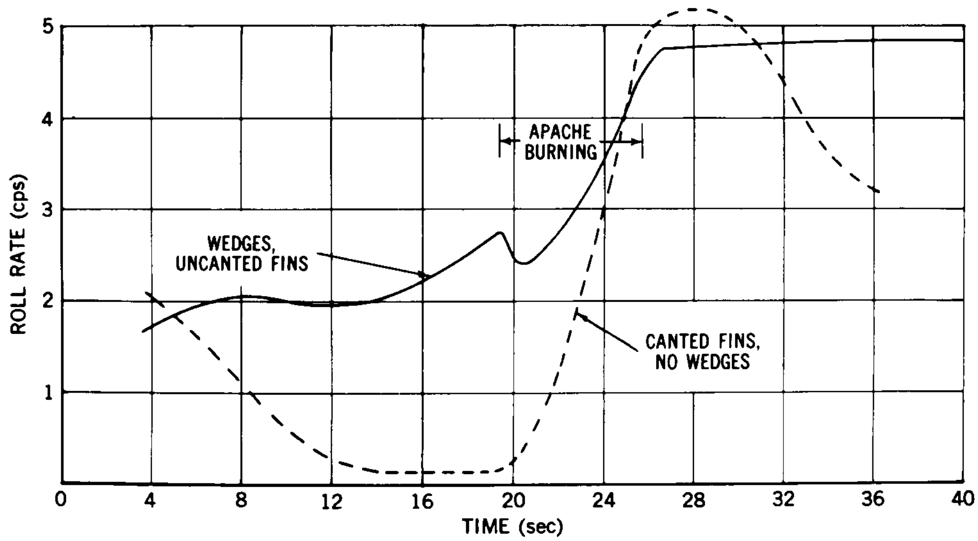


Figure 14—Roll rate vs. time (Note: data are taken from actual flight records).

The acceleration environment to which the payload is subjected is no more severe than that of the Nike Cajun. Figure 15 compares the maximum longitudinal accelerations imposed by the first- and second-stage boost phases. Since the Apache operates at a lower thrust level than the Cajun, the loading during second-stage burning is less. Lateral accelerometers flown on the Apache indicate that there are no significant vibrations transmitted to the payload during Apache boost. It should be remembered however that the Nike boost phase does subject the payload to rather severe lateral and longitudinal loads. Figure 16 is a playback of the actual loads recorded during a typical Nike boost. The longitudinal accelerometer was a ± 100 g instrument; the lateral accelerometer range was ±25g's. Data are shown only through Apache separation, as vibrations are not significant after this time. The environment shown in Figure 16 can be considered typical for the Nike Cajun or Nike Apache vehicles.

PERFORMANCE CALCULATIONS

All of the trajectory data contained in this report were computed on IBM 7090 digital computers using a three dimensional, n-stage particle trajectory program. This program was originally developed for Vanguard, and was modified and adapted for sounding rocket applications. These trajectories were computed for a nonrotating spherical earth and thus do not have Coriolis effects included.

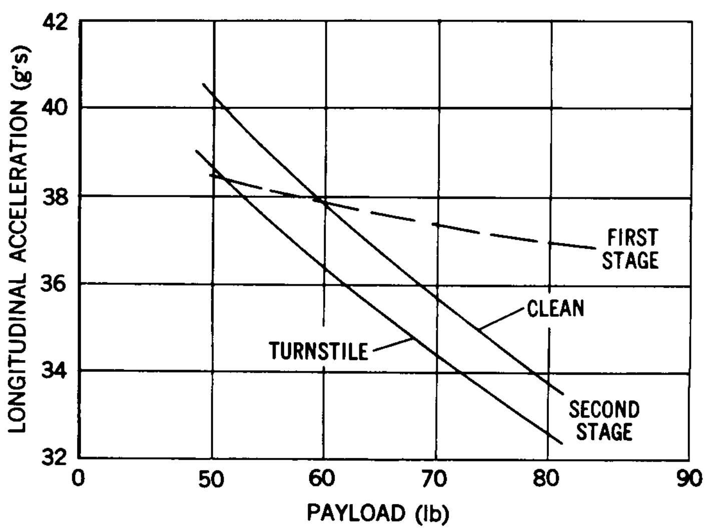
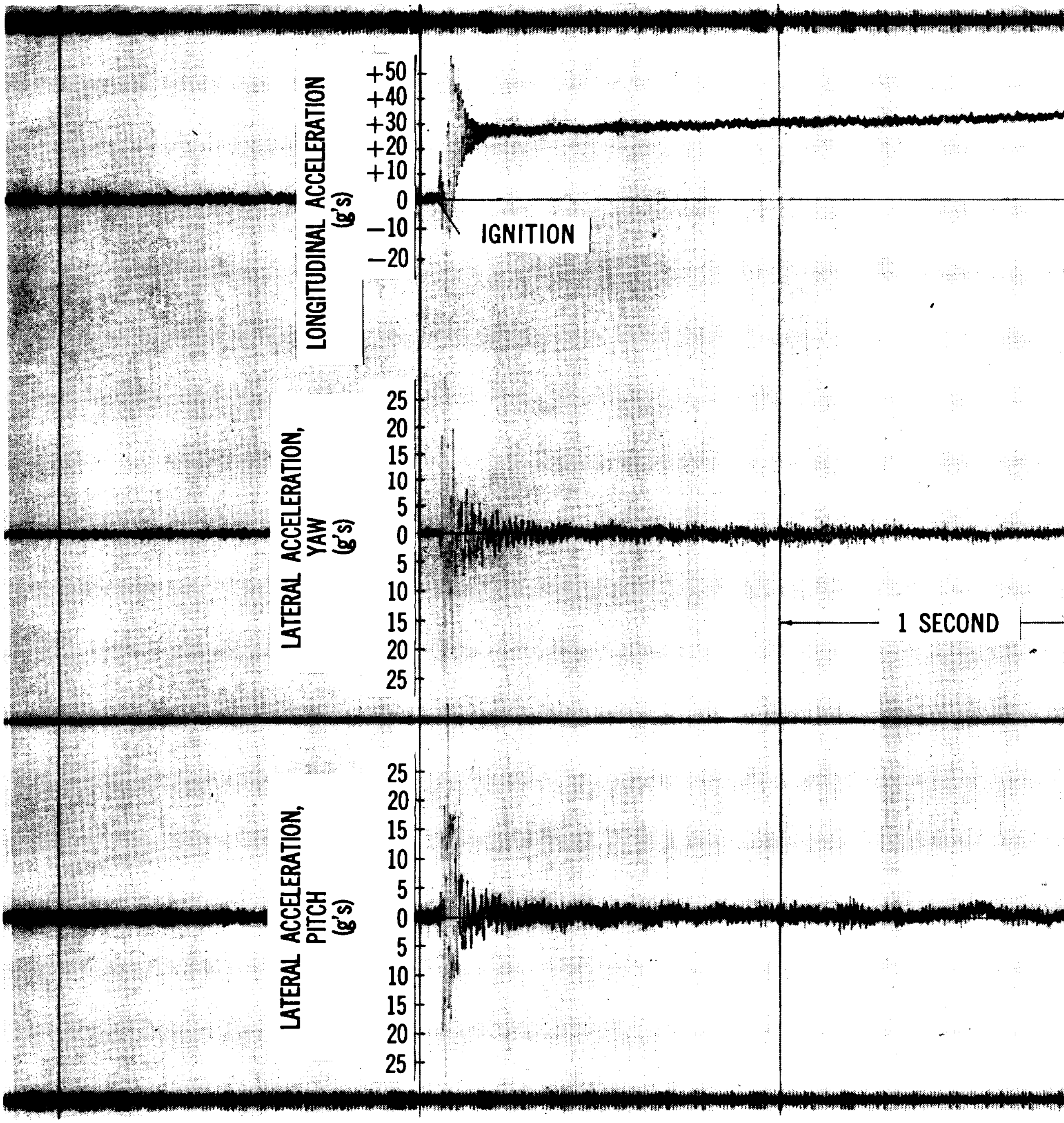


Figure 15—Maximum longitudinal acceleration vs. payload weight (sea level launch, 80 degree launch angle).



LONGITUDINAL ACCELERATION (g's)
+50
+40
+30
+20
+10
0
−10
−20
IGNITION
LATERAL ACCELERATION, YAW (g's)
25
20
15
10
5
0
5
10
15
20
25
1 SECOND
LATERAL ACCELERATION, PITCH (g's)
25
20
15
10
5
0
5
10
15
20
25

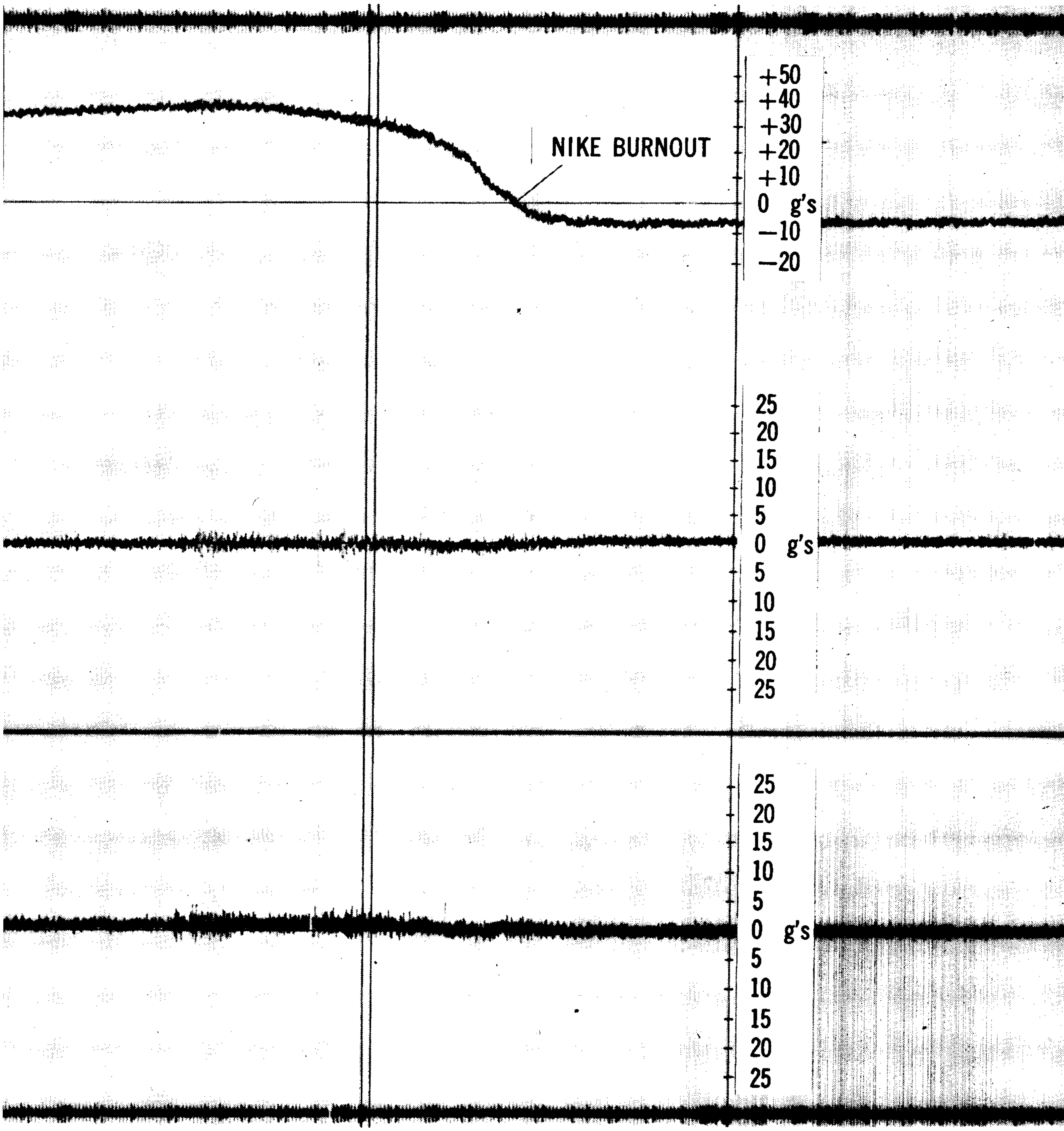


Figure 16—Typical first-stage boost environment.

The trajectory data contained herein are given for the purpose of indicating to the vehicle user the general range of performance that can be expected from the Nike Apache vehicle under various conditions of payload weight, launch angle, and launch elevation. An attempt has been made to include, for comparative purposes, trajectories that would be representative of the conditions found at the various missile test ranges currently used by NASA. Not all trajectories have been run for each case, but rather a sampling has been made to indicate the effects of altitude and launch angle on the maximum altitude. Since most contemplated launches of the Nike Apache will take place at the NASA Wallops Island facility, the bulk of the data presented is for conditions representative of this facility, namely, a launch angle of 80 degrees from a sea level elevation.

Figure 17 is a summary of the maximum altitude performance for the Apache for the three most commonly flown drag configurations. These consist of the basic vehicle with an 11 degree cone and (1) no antennas (clean), (2) two DOVAP antennas (of any length), or (3) four turnstile antennas swept at 45 degrees.

In all of the accompanying figures these configurations are referred to as "clean," "DOVAP," and "turnstile" respectively.

The data are presented for launch angles up to 90 degrees (vertical). The normal angle for a Wallops Island firing is 80 degrees. Except for special circumstances, this is the maximum launch angle Q_e permitted by range safety regulations for this type of vehicle.

As can be seen, drag has a severe effect on the performance of this system. For instance, there is a 26 mile altitude penalty associated with flying the four turnstile antennas on a 50 pound payload at 80 degrees Q_e. The addition of these antennas is responsible for a drag coefficient increase of 40 to 50 percent over that for the clean vehicle. Two DOVAP antennas add somewhat less drag but still impose a significant penalty. If the users of this system should ever require maximum altitude performance, the development of flush antennas would be necessary.

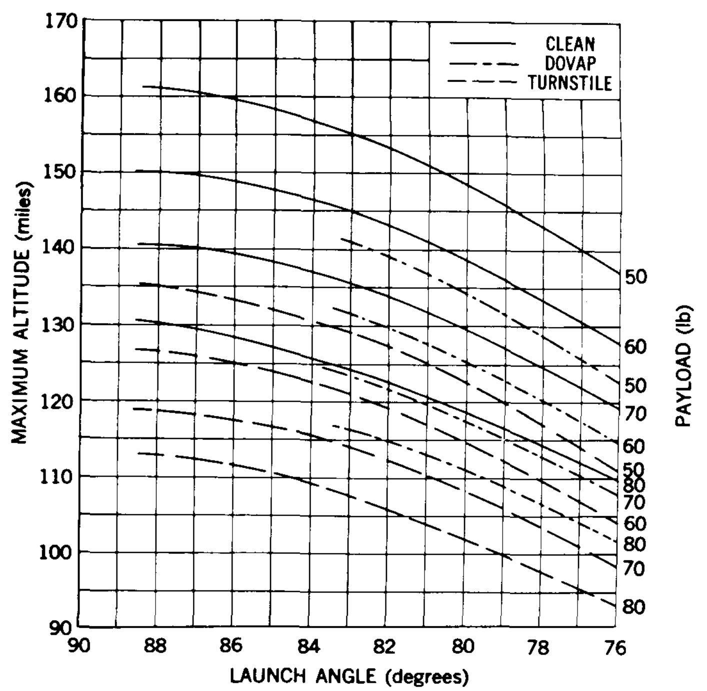


Figure 17—Maximum altitude performance for three drag configurations (sea level launch).

A second-stage ignition time of 20 seconds from lift-off was used in all of the trajectories from which the data in Figure 17 were extracted. This time was chosen as the result of an optimization study, the results of which are shown in Figure 18. Actually, there seems to be very little effect on maximum altitude resulting from variations of the coast time. The optimum is

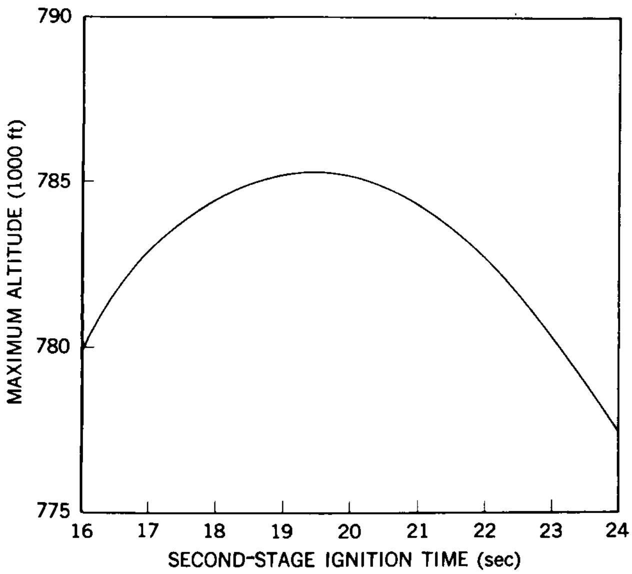


Figure 18—Effects on summit altitude of varying second stage ignition (sea level launch, 80 degree launch angle, 50 lb payload, clean configuration).

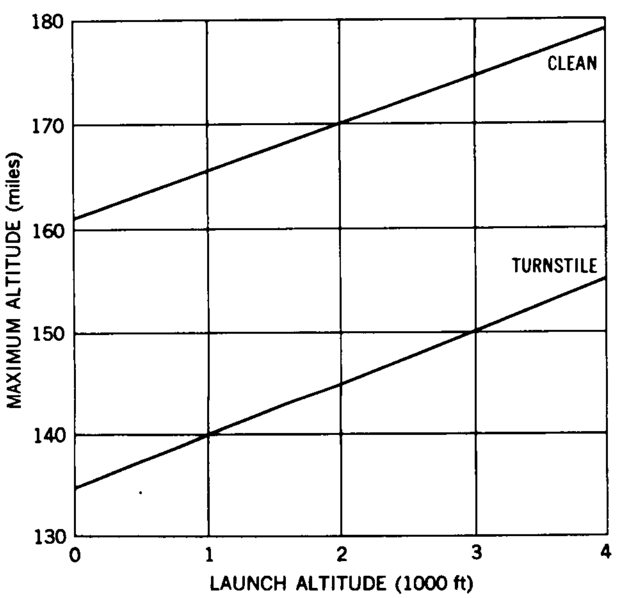


Figure 19—Variation in summit altitude with launch altitude (88 degree launch angle, 50 lb payload).

about 19.5 seconds; however, there is only about 1.5 miles difference in the theoretical apogee between the trajectories calculated with second-stage ignition times between 16 and 24 seconds. Ignition of the second stage at any time between these should not cause a significant deterioration of performance. Very short coast phases should be avoided as heating effects on the fins (and possibly the payload) may become critical.

Figure 19 illustrates the performance "bonus" that can be obtained by launching from missile test ranges located significantly above sea level. If White Sands Missile Range, which is about 4000 feet above sea level, were used for the launch site, an altitude increase of almost 20 miles for any given flight configuration could be expected.

The burnout velocity of the second stage varies from about 6000 to 7200 feet per second for the configuration considered (Figure 20). The very significant effects of drag can again be seen. Variation of the second-stage ignition time will have an effect on these velocities; however, the resulting change in the altitude-velocity profile will essentially even-out the drag impulse losses, and the total altitude performance will not be seriously affected (Figure 18).

The series of curves presented in Figures 21 through 24 represent the general altitude, velocity, range, and time characteristics of the Nike Apache for sea level launch at 80 degrees Q_e (Wallops Island). The significant coordinates of any given flight may be found by cross reference and plotting, and by interpolation.

Figures 21(a) and (b) present velocity versus time for the clean and turnstile configurations respectively. Data are plotted through 70 seconds. After this time the only significant force retarding the missile is gravity. It is interesting to note that, during the first coasting phase, the vehicle with the higher payload weight loses less velocity than that with the lesser weight. This is due to the effect of the "ballistic factor" $W/C_D A$, where W is the weight of the missile, C_D is the drag coefficient, and A is the cross-sectional area of the rocket. Figure 22 gives the velocity as a function of altitude up through 170,000 feet.

Altitude versus time and altitude versus range are plotted in Figures 23 and 24. These data are arranged so that, by interpolation and reasonable extrapolation, range-altitude-time for a wide variety of actual payload weights can be found. Again, these data are computed for the clean and the turnstile drag cases. Judicious use of these and other of the curves presented here should minimize the necessity for individual calculations of trajectories for specific payload weights as long as one of the "standard" aerodynamic configurations is flown.

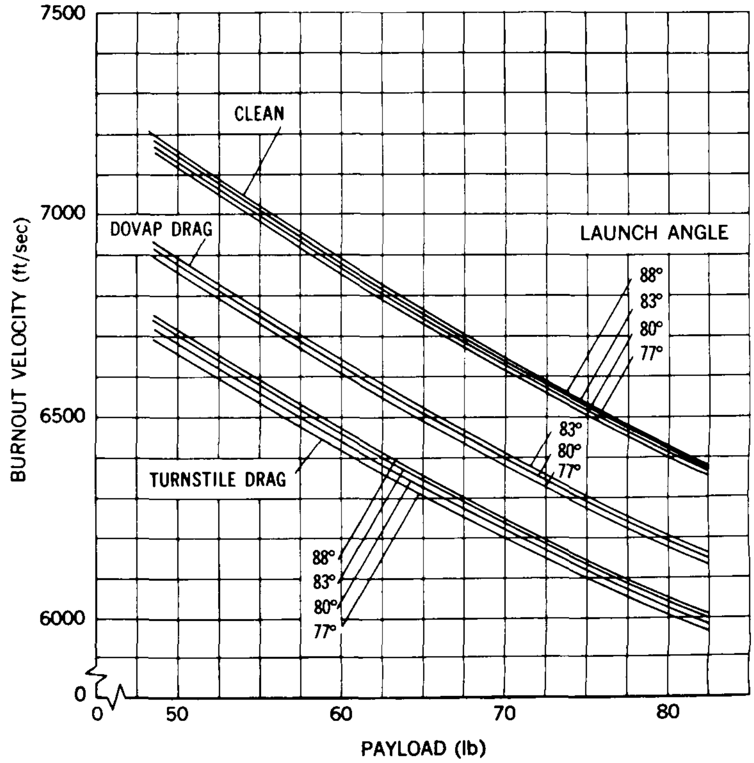


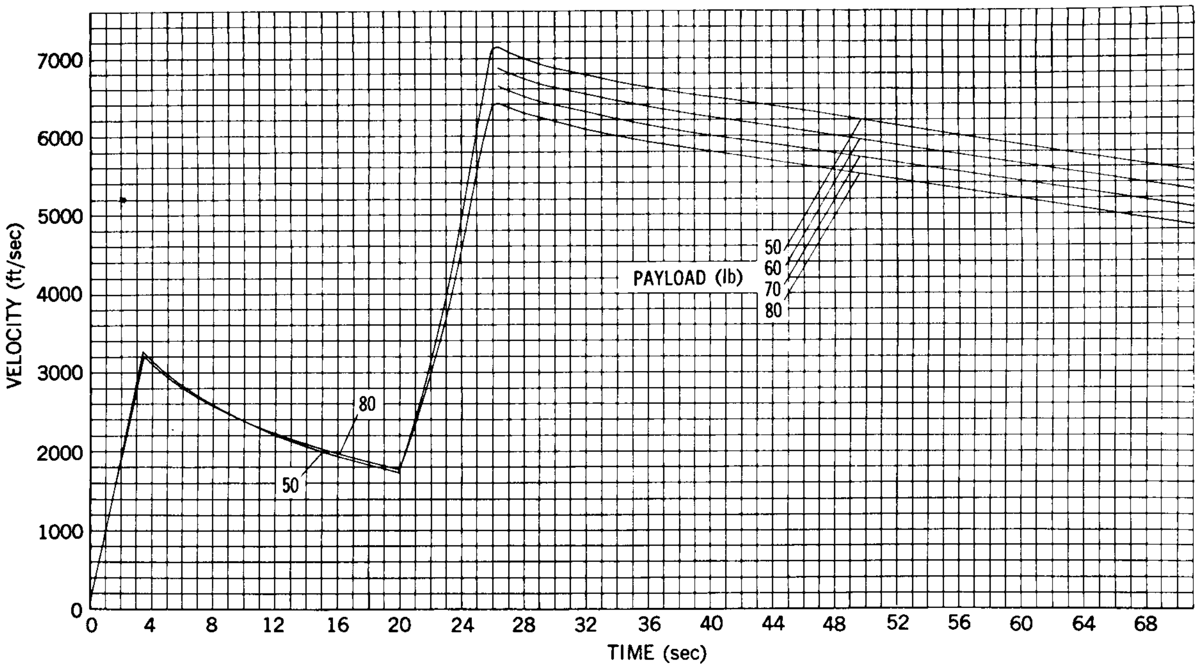
Figure 20—Burnout velocity vs. payload (sea level launch, ignition at 20 sec).

In the event it is desired to fly a payload that is either heavier or lighter than those shown in the foregoing figures, the approximate maximum altitude for these payloads may be obtained by the following method: Figure 25 is a plot of the altitude-weight factor versus launch angle. Suppose a payload of 95 pounds was to be flown on a Nike Apache with four turnstile antennas. From Figure 17, the maximum altitude for the above configuration with an 80 pound payload fired at 80 degrees Q_e is seen to be 102 miles. The altitude-weight factor from Figure 25 for an 80 degree Q_e and turnstile antennas is 0.67 mile per pound. The difference in payload weight is 95 pounds minus 80 pounds, or 15 pounds; thus

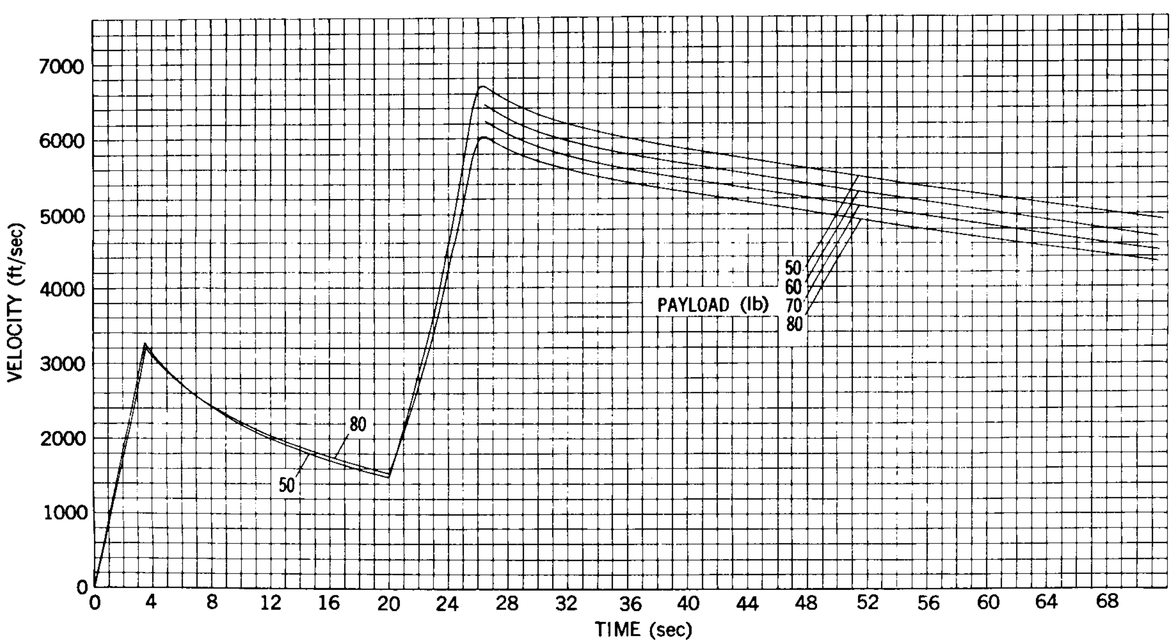
$$\Delta h = 15 \text{ lb} \times 0.67 \text{ mile/lb} = 10 \text{ miles}.$$

This is then subtracted from the maximum altitude for the 80 pound case to give 92 miles as the apogee for the Nike Apache fired at 80 degrees Q_e with a 95 pound payload and four turnstile antennas.

Figure 26 is a presentation of the variation in impact range with launch angle. These data are presented primarily for the benefit of range safety personnel who are concerned with the effects on range resulting from under- or over-correction of the rocket to winds. Once the vehicle is launched and the actual flight path known, this chart can be used to confirm that the impact error due to pitch-up (or down) is within specified dispersion limits.



(a) Clean



(b) Turnstile

Figure 21—Velocity vs. time (sea level launch, ignition at 20 sec).

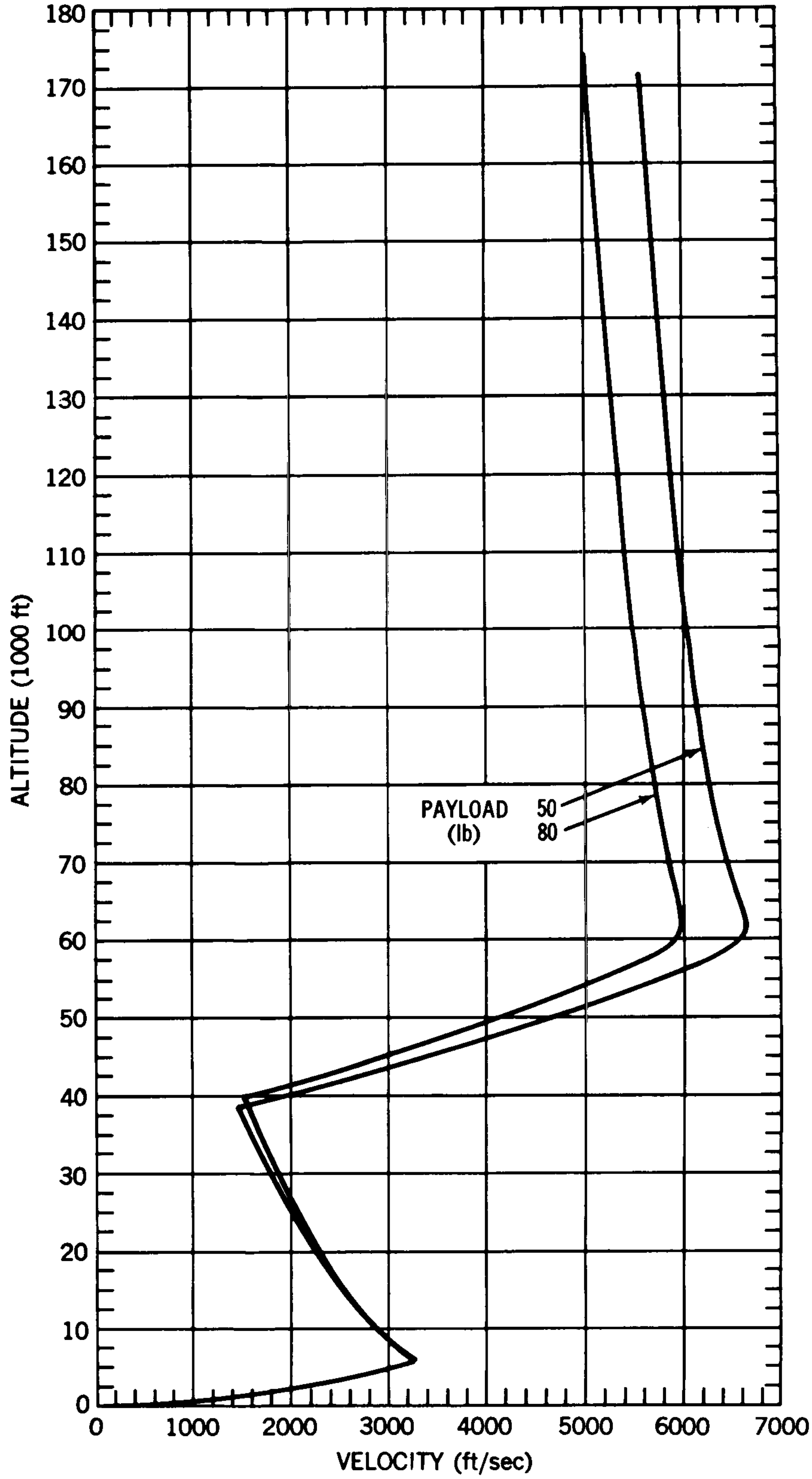
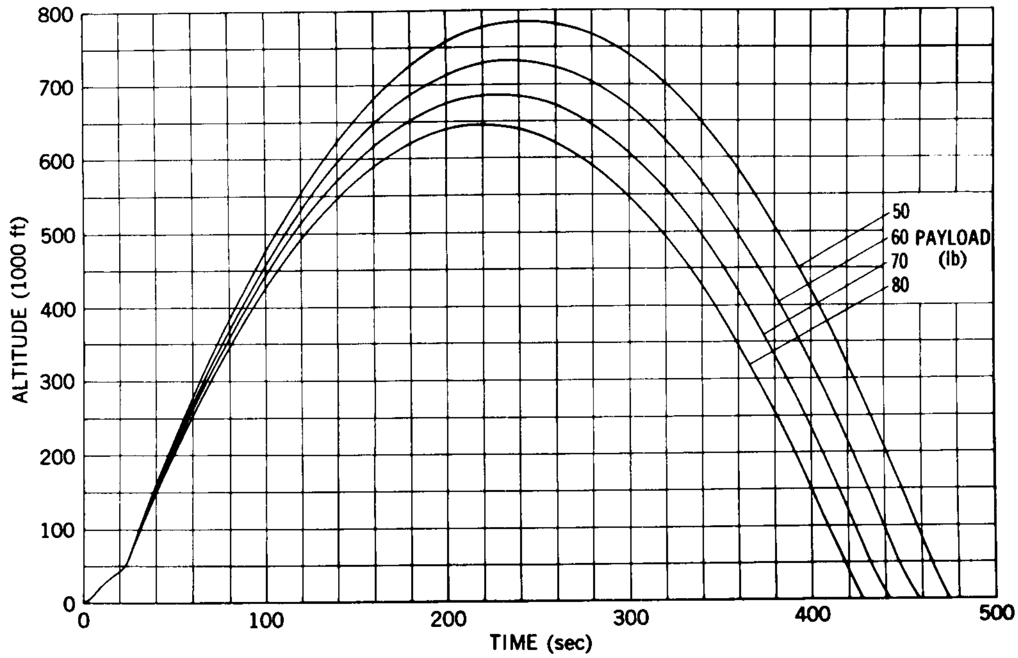
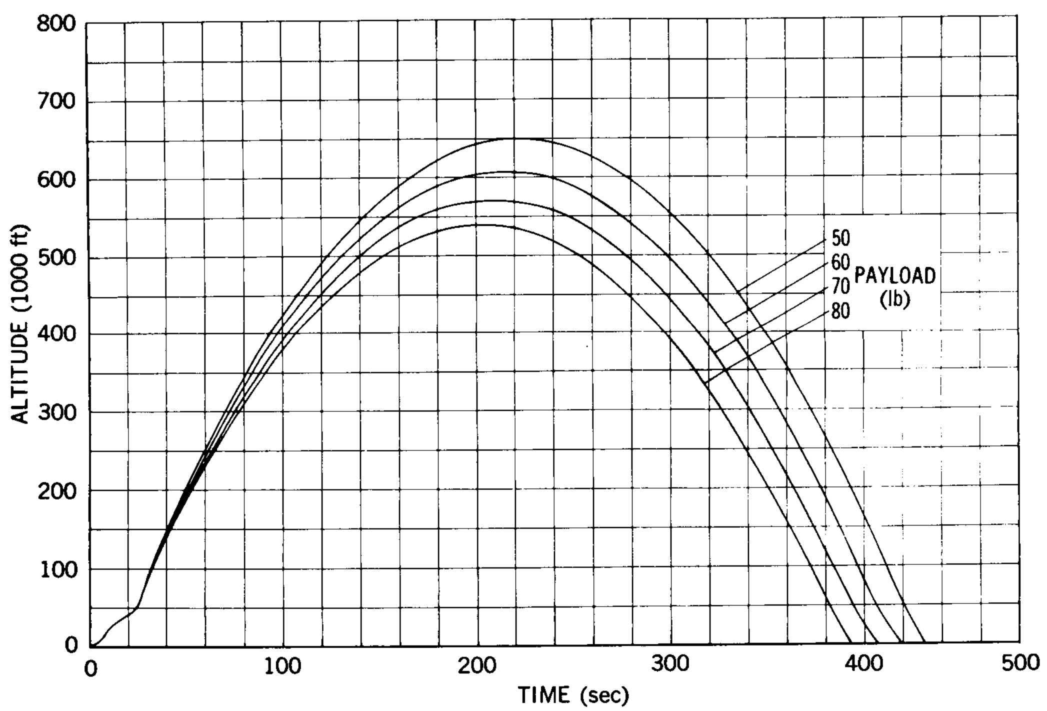


Figure 22–Velocity vs. altitude, turnstile (sea level launch, 80 degree launch angle).

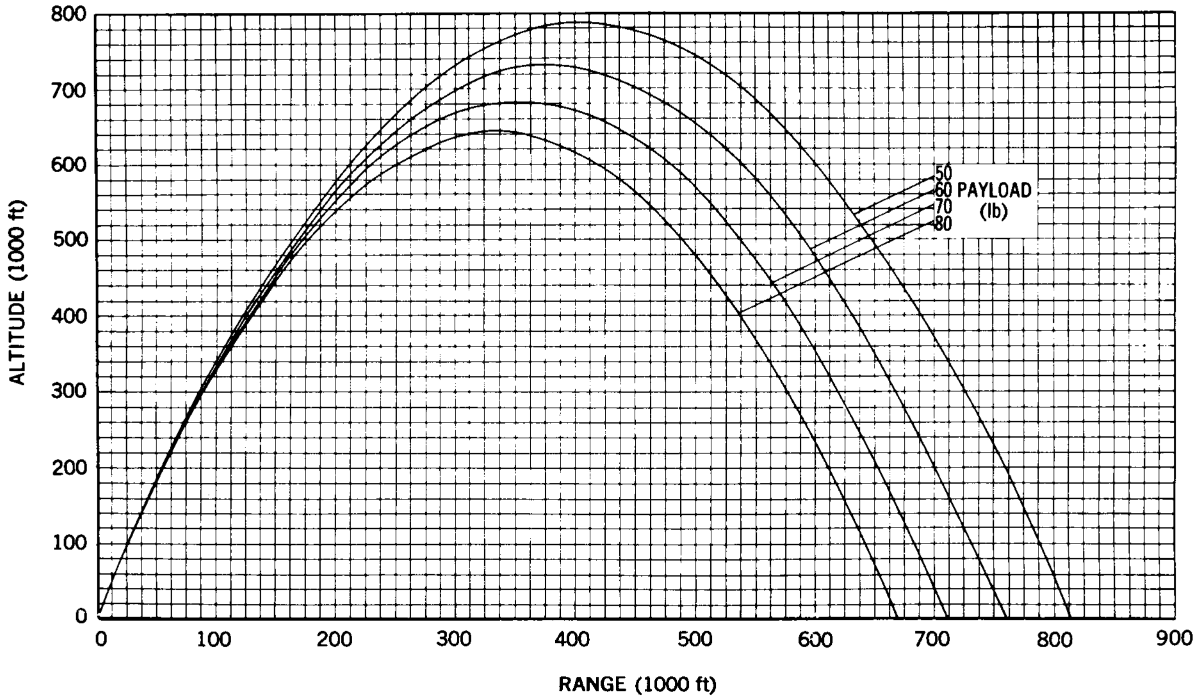


(a) Clean

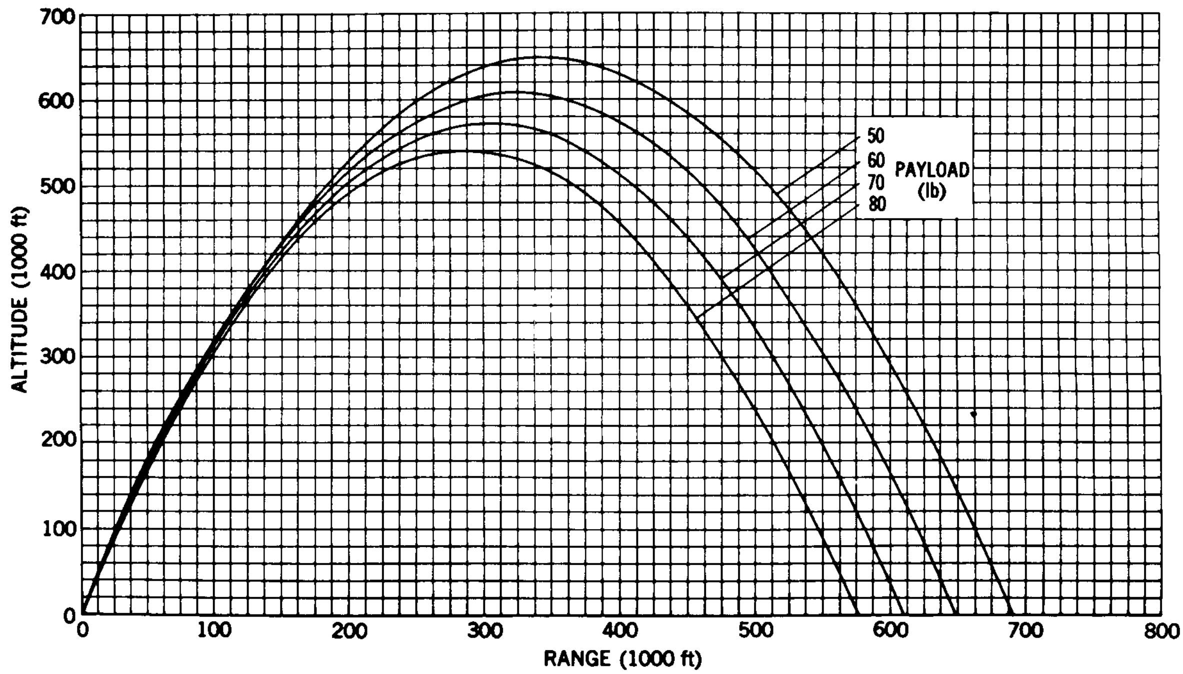


(b) Turnstile

Figure 23—Altitude vs. time (sea level launch, 80 degree launch angle).



(a) Clean



(b) Turnstile

Figure 24—Range vs. altitude (sea level launch, 80 degree launch angle).

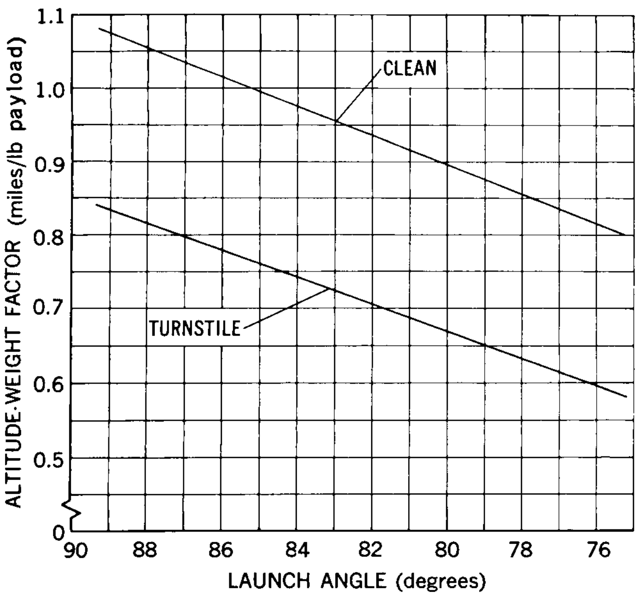


Figure 25—Altitude-weight vs. launch angle.

Figures 27(a) and (b) are "carpet" plots of the two most common drag configurations for which the summit altitude and impact range can be determined for any given payload and launch angle. Conversely, the approximate effective launch angle can be determined by knowing the summit altitude, impact range, and payload. It should be remembered that this method is only approximate, as altitude can be affected by variables not considered in the basic computational procedure. An example of this is the compromise in maximum altitude and range due to the excessive coning motion resulting from roll resonance.

The performance predictions may be considered to be accurate to within ±5 miles in maximum altitude. These data are based on particle trajectory calculations that do not account for performance disturbing influences, such as variation in motor performance, and aerodynamic asymmetries and appendages, each of which may have a noticeable effect on the observed performance of any given flight. Some variation in maximum altitude

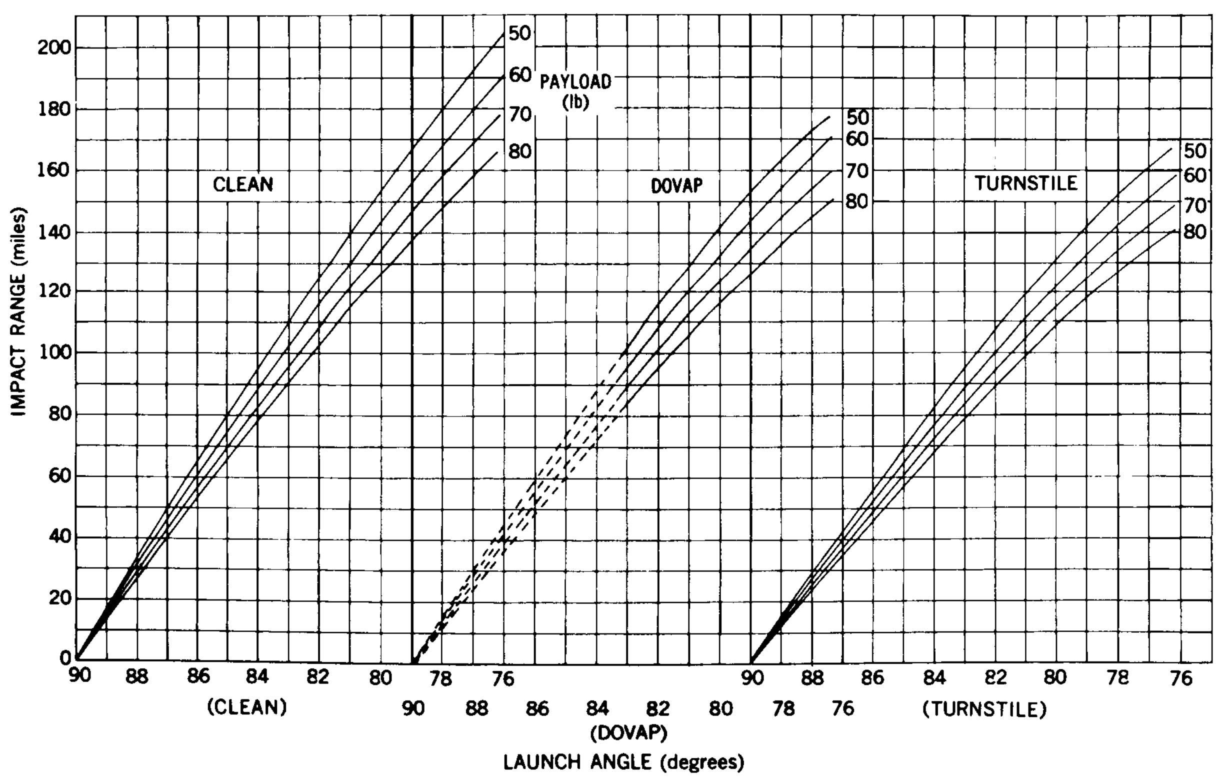
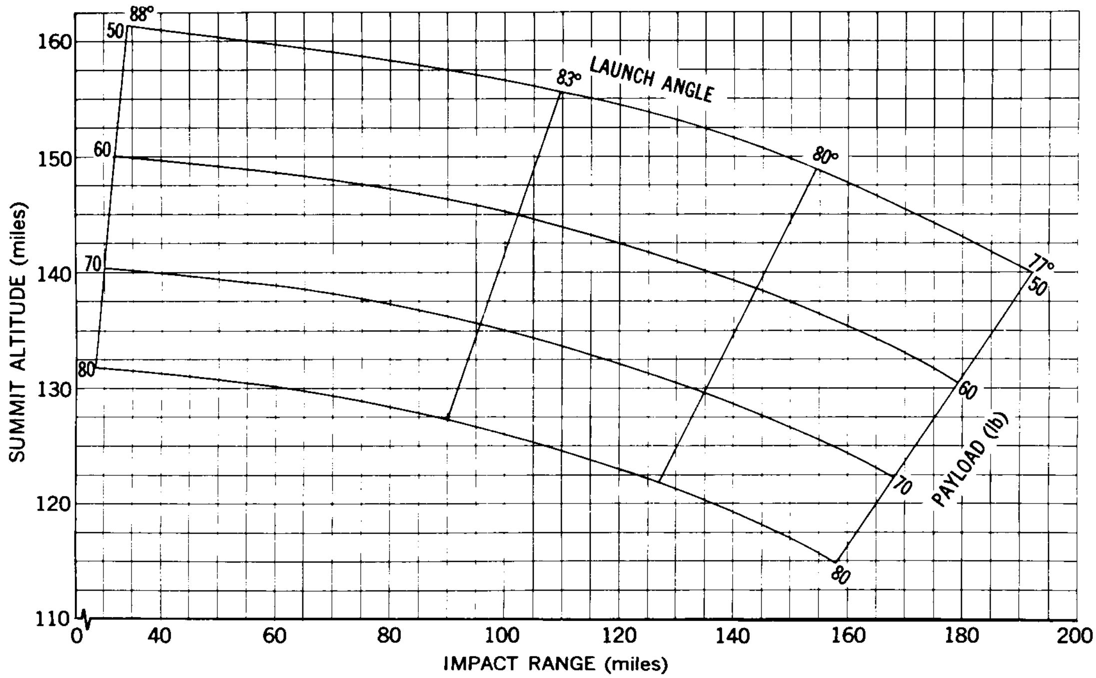
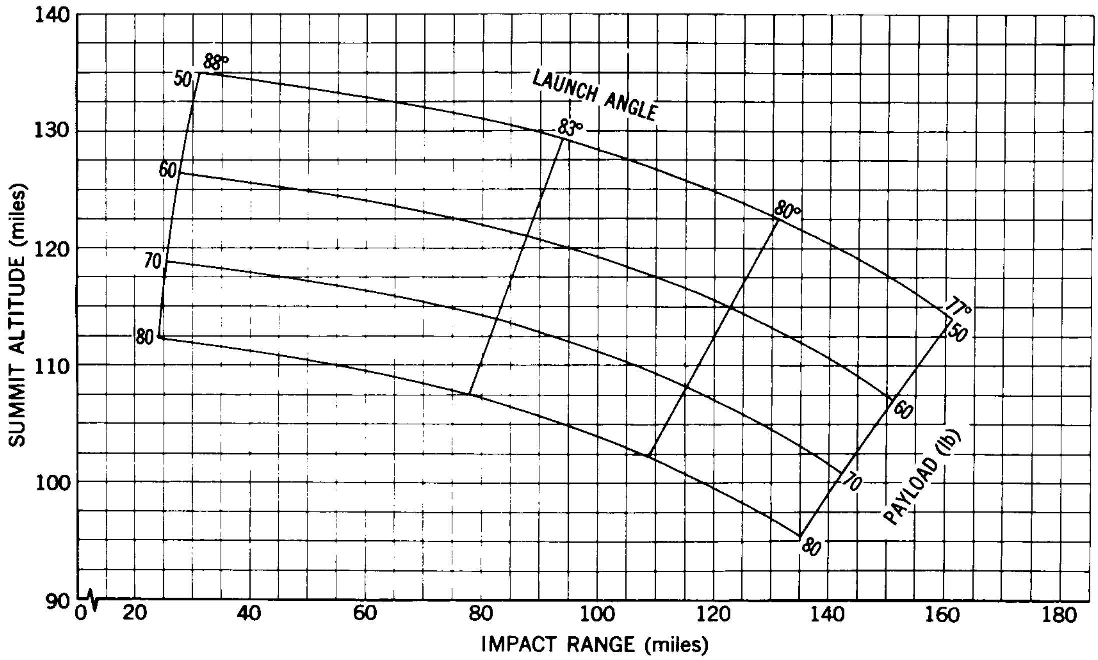


Figure 26—Impact range vs. launch angle.



(a) Clean



(b) Turnstile

Figure 27—Sea level launch.

may be observed as a result of deviation of the effective launch angle due to wind correction. The launcher is set to compensate for wind; nevertheless variations in effective launch angle of ±2 degrees are not uncommon. The altitude effects of this variation may be found from Figure 17 to be on the order of ±5 miles. Launch angle influence on impact range is of much greater magnitude. Reference to Figure 26 shows that this can be as high as ±15 miles per degree. Range and cross range uncertainties due to all effects (i.e., dispersion) are considered in Reference 5, which may be used for wind-weighting and dispersion for the Nike Apache.

CONCLUSIONS

The Nike Apache is a two-stage sounding rocket system for lifting scientific payloads to altitudes as high as 150 miles (240 km). Available payload volume of up to 2450 cubic inches is located primarily in a cylindrical section having a maximum internal diameter of 6.5 inches. Environmental conditions, to which the payloads are subjected, are similar to those of the Nike Cajun during first-stage boost; however longitudinal acceleration during Apache boost is less than that experienced during Cajun boost.

The Apache is characterized by configurational similarity to the Cajun and, in general, uses interchangeable hardware. Payload attachment at the Apache head cap is identical to that of the Cajun; thus payloads designed for use on the Cajun may be used without modification. Experimenters who are now using the Nike Cajun, and who have a requirement for higher altitude performance, will find the Nike Apache system well suited to their needs.

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